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FLUTTER, NOISE, AND BUFFET PROBLEMS RELATED TO THE X-15

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From an aeroelastic standpoint, the high Mach number capabilities of the X-15 and the associated aerodynamic heating presented two new problem areas. For instance, at the time of the initiation of the project no experimental flutter results were available above $M = 3$, and an adequate aerodynamic theory to use at these high Mach numbers had not been established. Thus, the X-15 has provided an impetus and focal point for research into these new areas, which of course is one of the purposes of such a project. With regard to aerodynamic heating, reduction in stiffness due to transient conditions has been relatively small. However, large reductions in stiffness were found due to permanent buckling of the skins which was induced by aerodynamic heating. Thus, the effects of aerodynamic heating could be incorporated into the aeroelastic problem simply as a reduction in structural stiffness, and small-scale models can be tested cold but with a reduced stiffness to simulate the hot condition. These reductions in stiffness were determined largely from laboratory tests on structural samples subjected to the load and the temperature-time history of the airplane recovery mission. For example, some of the reductions in stiffness were found to be as much as 60 percent.

In this paper, flutter, noise, and buffet problems will be considered. The flutter program will be examined first.

In figure 1 is shown a sketch of the X-15. The shaded areas are those components whose design was affected by flutter considerations. The remaining portion of the flutter section will be devoted to a discussion of various components.

The flutter test program is presented in table I. Dynamic models of the horizontal and vertical stabilizers have been tested in the Langley 8-inch hypersonic aeroelastic tunnel which utilizes helium as a test medium, in the 26-inch Langley transonic blowdown tunnel, in the Langley 9- by 18-inch supersonic flutter tunnel, and in the Langley 11-inch hypersonic tunnel. Full-scale tests of the tail surfaces were originally scheduled to be made on a ground-launched rocket to the maximum flight Mach number and also on a sled up to $M = 1$. These tests were deleted in favor of full-scale tests in the Langley 9- by 6-foot thermal structures tunnel at $M = 3$ and a

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stagnation temperature of 660° F. A research model of the wing has been tested throughout the Mach number range of 0.5 to 7 in the facilities listed. An addition to the original test program consisted in the testing of the influence of the wing-mounted X-15 on the flutter of the B-52. These tests were accomplished in the University of Washington wind tunnel.

The main lifting surface has not posed a problem with regard to flutter. Its stiffness is dictated mainly from thermal considerations and has resulted in a very stiff wing. The only changes were to the landing flaps; a positive up-lock was provided in order to increase the stiffness of the flap actuating system and an inner corrugated skin was used to provide a higher torsional stiffness of the flap. The flutter tests of the research wing, which, however, did not provide complete dynamic similitude, indicated a very wide margin of safety, as did the theoretical results for the full-scale wing.

Now, examine the results of the flutter studies of the horizontal stabilizer. The horizontal tail, being of the all-movable type in which its right and left sides could be moved differentially, appeared from the outset to constitute a major aeroelastic problem and will require detailed investigation. Early in the flutter studies, it was decided to move the axis of rotation forward from the 35-percent mean aerodynamic chord to the 25-percent mean aerodynamic chord in order to increase the flutter speed. In addition, the hydraulic actuator size was increased in order to increase the system torsional stiffness, since the compressibility of the fluid in the actuators constituted a weak link in the stiffness of the pitching degree of freedom. In addition, as determined from the laboratory tests mentioned previously, thermal buckling of the panels lowered the torsional stiffness to an unacceptable point. A reduction in rib spacing decreased the buckle depth to a point where the resulting stiffness level was satisfactory. More recently, reevaluation of the recovery mission indicated larger chordwise temperature gradients than were originally anticipated (gradients such that permanent skin buckles would occur). At the altitudes at which this would occur, the loss in stiffness would be permissible, but the stiffness loss from the permanent buckles would not be tenable at lower altitudes. To prevent this permanent buckling of the skin from the chordwise temperature gradient, the skin gage was increased approximately 20 percent.

The results obtained for the flutter of the horizontal stabilizer are given in figure 2. A stiffness-altitude parameter $\frac{b\omega_\alpha}{a}\sqrt{\mu}$ is plotted against Mach number M. In this parameter, b is the stabilizer half-chord, ω_α is the torsional frequency, μ is a mass ratio consisting of the ratio of the mass of the surface to the mass of a certain volume of air surrounding the surface, and a is the velocity of sound. The flutter or unsafe region is below the curves. In this figure, radial lines emanating from the origin represent constant-dynamic-pressure lines. The shaded area is the operating region of the X-15. The design q of 2,500 lb/sq ft is shown in figure 2. However, since the pilot must execute a pull-up at $M = 2.75$ to provide ground clearance, he will be operating at lower dynamic pressure than the 2,500 lb/sq ft given in this range. The bottom of the shaded area represents sea level. Now, examine the experimental results. These models were designed to simulate the loss in stiffness due to aerodynamic heating and were designed with a 40-percent reduction in torsional stiffness and a 60-percent reduction in bending stiffness. The open points represent no flutter and the solid points represent flutter. The series of open points in the range of $M = 0.8$ to 1.2 show no flutter up to the maximum q of the tunnel and show no intersection with the operating region. Flutter was obtained, however, from $M = 1.3$ to $M = 7$. It is interesting to note that there appears to be no pronounced transonic bump such as have been found in the past on other configurations. The open point with the cross at $M = 3$ was obtained from the full-scale tests of the tail in the Langley 9- by 6-foot thermal structures tunnel for a stagnation temperature of 660° F. Although no flutter was obtained, the test provided a good proof test since q was 3,400 lb/sq ft, well above the design value of 2,500 lb/sq ft. Now, examine the theoretical results. Two sets of calculations are shown; one using piston theory for the aerodynamic input for the high Mach numbers and one using the three-dimensional kernel function for subsonic Mach numbers. Excellent agreement with experiment has been found for the range of $M = 2$ to 7. The usual modal type of analysis was not used here but instead the piston theory was used to formulate the aerodynamic influence coefficients and these combined with the structural influence coefficients provided a procedure whereby the flutter speed was obtained directly by iteration as given in reference 1. The subsonic portion was obtained by the use of the usual modal approach except that the three-dimensional kernel function (ref. 2) was used for the aerodynamic input. That is, the plan form of the tail as well as the effects of compressible flow were taken into account up to $M = 0.95$. These results have been obtained at 0° angle of attack.

Some calculations using piston theory for the effect of angle of attack on flutter have indicated a possible enlargement of the flutter region. (See fig. 3.) Calculated results are given in figure 3 for $\alpha = 0^{\circ}$, 10°, and 20°. The effect of angle of attack is destablization and becomes larger as the Mach number is increased. However, the section of each curve that is solid is believed to be within the limitation of piston theory. This limitation is fixed by the ratio of

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the normal velocity of the airfoil to the local speed of sound; this ratio must be less than unity.

A research program was set up to investigate the ranges of validity of piston theory. In figure 4, the stiffness-altitude parameter $\frac{b\omega_\alpha}{a}\sqrt{\mu}$ is plotted against the ratio of bending frequency to torsion frequency $\frac{\omega_h}{\omega_\alpha}$. The model had an aspect ratio of 1, was rectangular and rigid, but was mounted on a flexible shaft. The airfoil sections were symmetrical double wedges with thickness ratios of 5, 10, and 15 percent. The experimental result of the 5-percent-thick wing is in remarkable agreement with theoretical predictions. The 10-percent experimental result is about 5 percent below that of the theoretical result, but the 15-percent-thick model is about 16 percent below the theoretical result. This curve points out the validity of using piston theory for the wing with smaller thickness ratio at zero angle of attack. However, for the 15-percent-thick wing the slope of the surface is such that limitation of piston theory is exceeded, that is, the ratio of the downwash to the speed of sound exceeds unity. In figure 3, sections of the curve for which w/a is less than 1 are shown solid. In figure 3 the results of an experiment on the horizontal tail are shown. The tail was set at 11° angle of attack and the tunnel density increased. The test was terminated at the circular point without flutter. Thus, it appears that the X-15 will be safe from flutter at the higher angles of attack. However, this effect of angle of attack does constitute a research area requiring additional theoretical and experimental work.

With regard to the vertical surface, no experimental flutter has been obtained in the transonic and supersonic range, even though in one case the stiffness of the spindle attachment was reduced to about 15 percent of the design stiffness. Calculations indicate a very large flutter margin. However, flutter was obtained at $M = 7$ but with a large margin of safety. This wedge configuration appears to be a rather stable airfoil section from a flutter standpoint. So far, no flutter has been found on the dive brakes, either classical or buzz. However, difficulty has been experienced in modeling the dive brakes. In attempting scaling to obtain the minimum expected frequency, the dive brakes could not take the static load in the open position, and the springs simply deformed until they hit the stop. Some new models are being built utilizing measured frequencies which permit a higher stiffness in the open position to further study the problem.

With regard to panel flutter, it does not appear that a problem exists. In using the criterion presented in reference 3, for the flutter of flat panels, all panels appear to be in a safe region

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except one which is located at the forward end of the tunnel. However, this panel has a large amount of curvature which should raise the flutter speed a considerable amount above that of the flat panel. No panel flutter was observed on the full-scale test of the horizontal tail.

Up to this point, the X-15 has been considered. Originally, the X-15 was to be installed on the B-36. Later, however, it was decided to use the B-52 as the carrier airplane; and, of course, the question immediately is raised as to what will be the effect of this asymmetrically placed mass on the flutter of the B-52. Since Boeing had a flutter model of the B-52, it was decided to conduct tests of this combined configuration. These tests were conducted by Boeing and were made in the University of Washington wind tunnel. The X-15 model was rigid but was scaled for total inertias and mass. The pylon, however, was scaled to provide the proper frequencies. The results of these tests are shown in figure 5 in which altitude is plotted against Mach number. These tests were made at $M = 0.2$ and then extrapolated to the higher Mach number condition. The airplane flight plan is shown as well as the flutter boundary for two conditions. Both of these boundaries contain a 15-percent margin in velocity. First, the flutter boundary was determined for the airplane having its take-off weight throughout the flight, and there appeared to be an adequate margin of safety. The fuel consumption was then simulated for the various altitudes, and the second curve indicates these results. An even larger margin of safety is found. Three pylon stiffnesses were investigated in these tests, and no appreciable change in the flutter speed was found. Thus, it appears that the location of the X-15 on the B-52 does not create a flutter problem.

In addition to the problem of the influence of the X-15 on the B-52 flutter speed, there still remains the problem of the effect of noise from the two inboard engines of the B-52 on the X-15 especially during take-off, as well as the buffeting of the horizontal tail of the B-52, as induced by the presence of the X-15 ahead of the tail. With regard to noise, the noise field produced by the B-52, as well as a sketch of the location of the X-15, is shown in figure 6.

It is to be noted that the wing of the X-15 is located in a very severe noise environment of the order of 156 decibels, and the tail is very close to the 156-decibel curve. Typical structural components of the X-15 are now being tested in a discrete frequency noise facility. These tests have been conducted at a decibel rating of 158. Unfortunately, on the first test the thermocouples failed after 10 minutes and the specimen failed after 1 hour of testing. On a second series of tests, the thermocouple staple spacing was reduced to one-third of the original spacing, which has now been found to be

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satisfactory. On a second specimen, failure occurred after 1/2 hour of testing, even though the skin thickness had been increased by 20 percent. Additional testing and detailed examination of the structure are planned in order to extend the service life of the airplane. However, if this problem continues to be important, there remains the possibility of attempting to reduce the sound field of the B-52. There are two obvious methods of doing this. First, reduce the engine power during take-off. It appears practical to obtain a 6-decibel drop by this method. Another procedure would be to add tailpipe extensions to the two inboard engines in order to remove the severe sound field of the B-52 from the X-15 structure.

Of course it must be remembered that the time duration of each take-off is measured in seconds rather than hours, so that the structure may be able to withstand the noise for these short periods.

No information as yet has been obtained of the influence of the X-15 rocket motor on the structure surrounding the engine. The near-noise-field measurements are in progress, and in these tests the engine is mounted in an aft fuselage. Thus, the effect of the noise field on the actual structure will be determined.

With regard to buffeting, some studies have been made of the influence of the X-15 on the B-52 horizontal tail. These tests were conducted by William J. Alford, Jr., and Robert T. Taylor, who have already reported on the force tests in a previous paper. No attempt was made to scale dynamically the horizontal stabilizer. However, a flexible right-hand stabilizer was installed on the B-52 model and instrumented with a strain gage at the root and one pressure cell was installed at approximately 60 percent span.

The root mean square of the bending moment was obtained for various configurations. Some of the results are plotted in figure 7 where C_L is plotted against Mach number. Flight buffet limit is shown for the full-scale B-52. The results of the model test are shown for $M = 0.4$, 0.75, and 0.820. From the model test at $M = 0.4$, it is actually possible to establish the buffet boundary, and the comparison with the full-scale airplane is excellent. The other two curves indicate the limit of the model tests, and no appreciable buffet was found at either of these places. The flight envelope is shown here and appears to be in a buffet-free region. Therefore, based on these model tests, at least, it can be concluded that there should be no buffet problem.

In conclusion, the flutter program has been discussed in detail, and with the modifications that have been made on the airplane, it appears that the airplane will be safe from flutter. Noise, on the other hand, could still remain a service problem, but methods of moving the noise environment from the tail do appear practical if it becomes necessary. Buffet tests of the influence of the X-15 on the B-52 tail indicate that there should be no problem.

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TABLE I.- FLUTTER TEST PROGRAM

Configuration	M	Scale	Test facility
Horizontal and vertical stabilizers			Langley:
	7	1/12	8-inch hypersonic aeroelastic tunnel
	0.85 to 1.3	1/12	26-inch transonic blowdown tunnel
	1.3 to 4.0	1/12	9- by 18-inch supersonic flutter tunnel
	3	Full	9- by 6-foot thermal structures tunnel
	7	1/12	11-inch hypersonic tunnel
Wing			Langley:
	0.5 to 1.2	1/15	2- by 2-foot transonic flutter tunnel
	1.2 to 2.0	1/15	9- by 18-inch supersonic flutter tunnel
	5	1/15	9-inch gas dynamics tunnel
	7	1/20	8-inch hypersonic aeroelastic tunnel
X-15/B-52	0.2	1/20	University of Washington wind tunnel

COMPONENTS AFFECTED BY FLUTTER

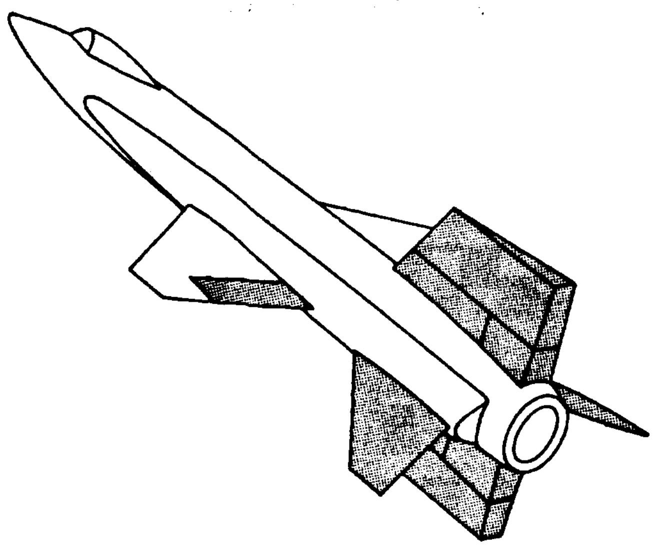

Figure 1

FLUTTER OF HORIZONTAL STABILIZER

$\alpha = 0°$

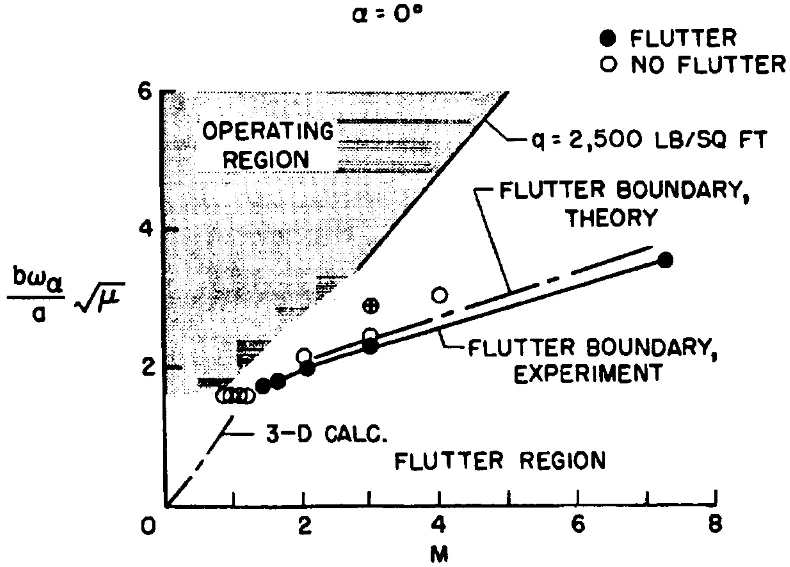

Figure 2

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EFFECT OF ANGLE OF ATTACK ON FLUTTER
OF HORIZONTAL STABILIZER

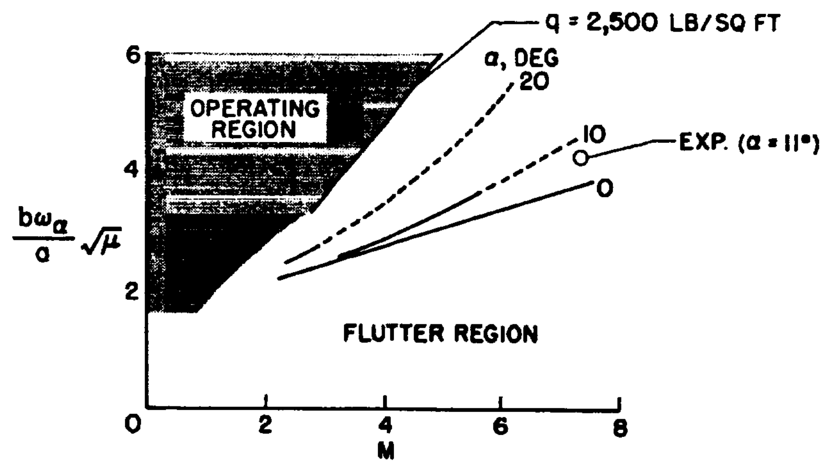

Figure 3

FLUTTER OF A DOUBLE WEDGE
RECTANGULAR; A=1; M=7

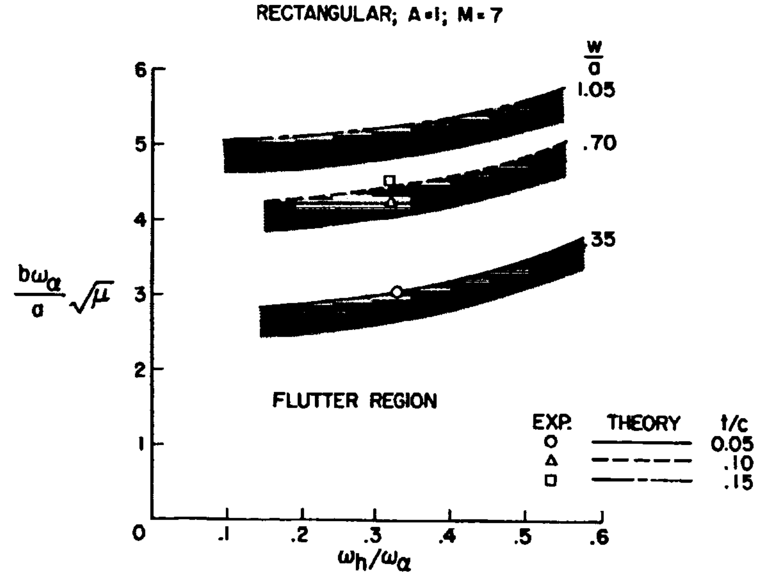

Figure 4

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FLUTTER OF X-15/B-52

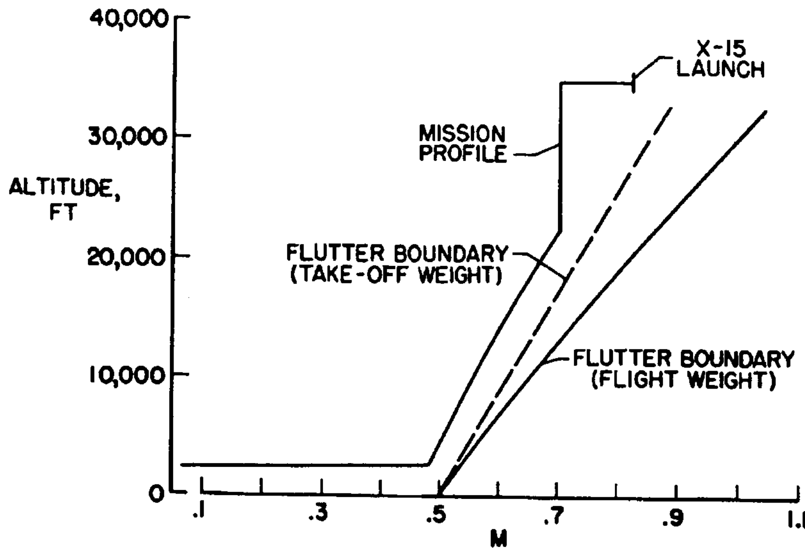

Figure 5

SOUND LEVEL DURING TAKE-OFF

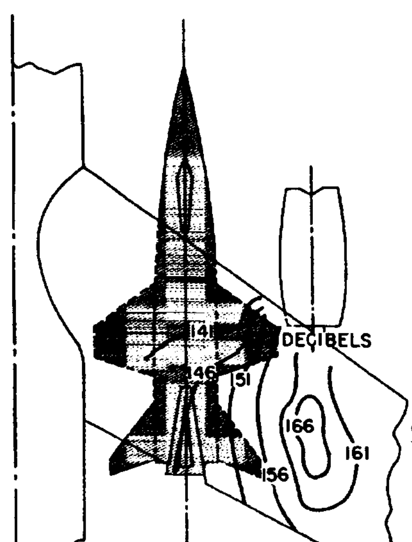

Figure 6

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X-15/B-52 BUFFET BOUNDARY

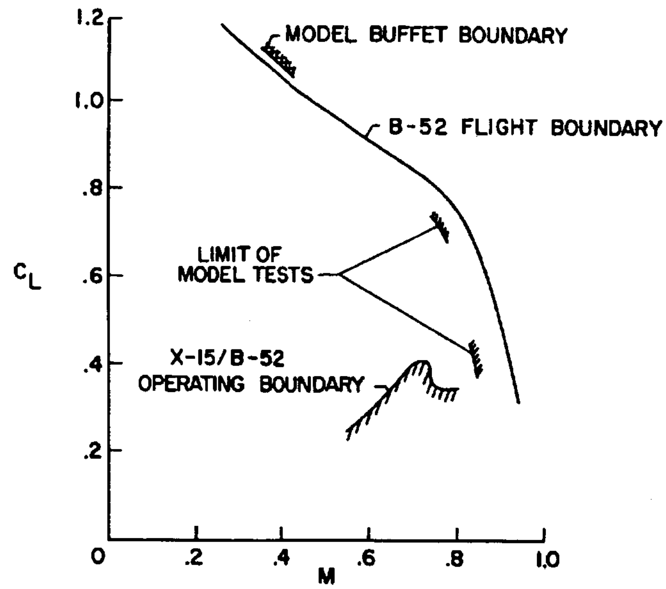

Figure 7

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